REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
					19b. TELEPHONE NUMBER *(Include area code)*

Proceedings of Meetings on Acoustics

ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Acoustical Oceanography
Session 2aAO: Seismic Oceanography

2aAO4.   Exploring the shelf-slope dynamics in the Adriatic Sea using numerical models and seismic oceanography (SO)

Andrea Bergamasco, Francesco M. Falcieri, Jeffrey W. Book, Sandro Carniel*, Warren T. Wood, Mauro Sclavo and Richard W. Hobbs

*Corresponding author's address: Oceanography, CNR-ISMAR, Venice, 30122, Veneto, Italy, sandro.carniel@ismar.cnr.it

  Dense shelf waters are formed and spread in the Adriatic Sea during winter periods, which dynamics are usually investigated by means of sea truth campaigns and modeling efforts. The former are either based on observational approaches (moored instruments, CTD, current meters, etc.) or on more innovative techniques, e.g. employing Seismic Oceanography. Recent studies have shown that SO techniques can produce maps of vertical transects along the survey lines with horizontal and vertical resolution of, respectively, 10 and 100 m, suitable to explore the horizontal structures of BBL dynamics. Elaborating on these considerations, a novel approach combining the SO dataset collected during the ADRIASEISMIC cruise and high-resolution numerical model (ROMS) results was performed in two restricted areas of the Adriatic Sea: off the Gargano promontory and off the Bari shelf break. We present the first steps along the definition of a novel methodology. On one hand SO can help to image the existing dynamical structures and their spatial/temporal resolution; on the other, the numerical model can quantify these acoustic snapshots in terms of temperature, salinity and density, integrating the XBTs that are acquired during SO lines, and help identifying the nature of other processes (e.g. turbulence, internal waves, etc.).

THE ADRIATIC SEA FRAMEWORK

The Adriatic Sea is a semi enclosed, marginal basin within the Mediterranean Sea, characterized by having two different water mass formation processes. Wintertime Northern Adriatic Dense water (NAdDW) mass formation process occurs in the northern half of the basin over the continental shelf, while open ocean deep convection occurs in the southern Adriatic. NAdDW flows southward gently increasing its depth, forming a "bottom trapped gravity currents", an energetic vein (or a series of veins) which flow is geostrophically adjusted.

The NAdDW is formed in winter in the shallow northern-central shelf region, during outbreaks of cold and dry Bora winds that induce strong evaporation and cooling. It is defined by wide range of T and S, depending on the regional and meteorological characteristics. This dense water mass is known to flow southwards along the isobaths of the Italian continental shelf and slope at depths of 80 –150 m and to exit through the Otranto Strait into the Ionian Sea. Details of the evolutionary characteristics of this coastal underflow can be found in Carniel et al., (2012).

In the topographically controlled cyclonic gyre of the southern basin, deep ocean convections (up to depths of 700 m) generate the Adriatic Bottom Water, mainly formed by the mixing of surface water of Ionian origin with relatively warmer and more saline waters (called Modified Levantine Intermediate Water) that enters the region at intermediate depths of 200-400m along the eastern part of the Otranto Strait. The NadDW, transported southwards as a vein of dense underflow, also contributes to this process through its mixing with local subsurface waters. However, the NAdDW pathway from its formation site to the southern part of the basin is not often clearly supported by observations, and does not happen regularly every winter. In addition to the winter cooling intensity, preconditioning of the intermediate and deep water masses generated by mixing of MLIW (warmer and saltier) with NAdDW (colder and fresher) prior to the winter convection may play a very important role in the dense water mass characteristics of the central basin.

SEISMIC OCEANOGRAPHY

In the past 50 years Multichannel Seismic Reflection (MSR) has been widely used by geologist and oil industries to investigate the structure of the Earth interior. Gonella and Michon (1988) described the internal waves in the eastern Atlantic by means of seismic reflections. Those reflection, caused by changes in water impedance, have been associated (Holbrook et al., 2003) to fine-scale thermo-haline features of the water column structure at the boundaries between water masses with different physical properties (i.e. temperature and salinity) defining a new cross discipline called Seismic Oceanography (SO). Water impedance reflects vertical changes in sound speed and water density, hence in temperature and salinity. Sallarès et al (2009) computed that the mean contribution of temperature and salinity to variations of impedance is in the order of 80% to 20% with a significant variability depending on local conditions. Nandi et al. (2002) compared seismic reflections to temperature profiles (obtained by XBTs) of the Norwegian Sea and highlighted a direct relationship to temperature contrasts as small as 0.03°C. Even if classical CTD casts are much more accurate, SO profiles produce a near synoptic image with a vertical resolution up to 10 -15 m (or even higher depending on the instrument configuration, Hobbs et al., 2009) and an horizontal domain in the order of tens of meters (Nakamura et al., 2006). Recently many articles have been using SO to study different aspects of the oceans dynamics, e.g. the Mediterranean outflow in the Atlantic Ocean (Hobbs et al., 2007; Papenberg et al., 2010) and in the Adriatic Sea (Carniel et al., 2012).

THE NUMERICAL MODEL IMPLEMENTATION

To study the dynamics of the NAdDW in front of the Gargano Peninsula a dedicated research cruise (ADRIASEISMIC) for hydrodynamical and seismic measures was performed during winter 2009. Some of the data already presented in Carniel et al. 2012 can be further analyzed with the help of a series of numerical simulations. The numerical tool used is a three dimensional hydrodynamic model, more specifically the Regional Ocean Modeling System (ROMS) in its 3.5 version. ROMS is a primitive equation ocean model (with free surface and hydrostatic approximation) that has an horizontal orthogonal curvilinear grid and a terrain-following stretched coordinates; a detailed description of the model code can be found in Benetazzo et al., 2013 and Boldrin et al., 2009.

Several runs with different bathymetries (uniform slope of 0.2% vs realistic topography), initial and open boundary conditions (idealized, interpolated from a full basin model or with and enhanced dense water, i.e. the dense water at the northern OBC have an increased density and momentum) were performed in order to cover a progressively more realistic description of the dynamics of dense waters. Horizontal, vertical grid settings and model
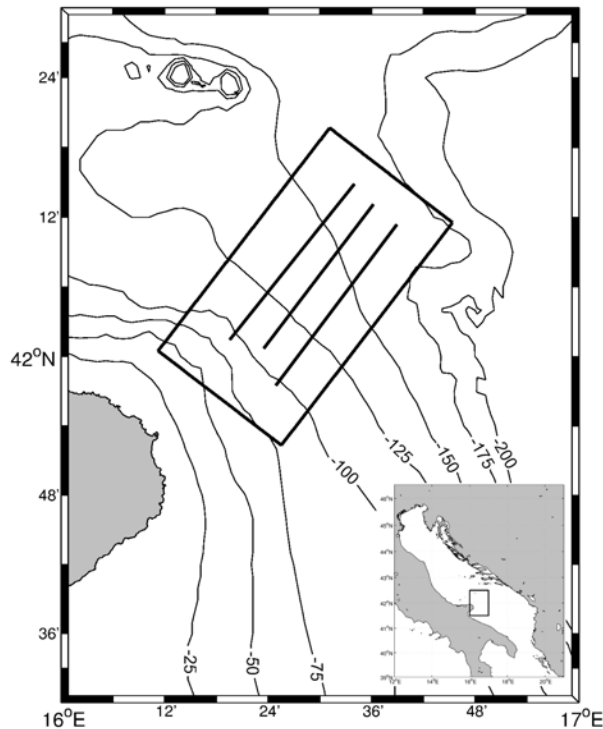
FIGURE 1. The investigated area: bathymetry and its location in the Adriatic Sea. The black box is the model domain (45x25 Km, with an horizontal resolution of 250 m) and the three lines represent three of the seismic lined measured during the ADRIASEISMIC 09 cruise. For a complete documentation of the cruise see Carniel et al., 2012

implementation have been kept the same for all simulation. Each run presents the same horizontal grid (100 x 180 nodes or 25 x 45 km, see Figure 1) with a constant grid step of 250 m and a variable vertical resolution; the 25 vertical levels have been stretched so that the maximum vertical resolution is focused near the sea floor. The physical implementation for advection of tracers considers a recursive MPDATA scheme and harmonic horizontal diffusivity. Pressure gradient, density computation through a non linear equation of state and vertical mixing parameterization follow Falcieri (2012).

In the present contribution only results from the more comprehensive run will be discussed and analyzed. It is a downscaled experiment that includes real bathymetry, boundary fluxes from a coarse full basin model, tidal forcing, and characterized by an analytical prescribed dense water inputs at the northern open boundary(this is done in order to compensate for a weaker NAdDW signal resulting from the interpolation during the downscaling procedure).

The Synthetic Seismic Reconstruction

In Figure 2 some of the model results are shown, specifically referring to hourly averaged fields (March, 8th, 2009 at 16:00 UTC) which corresponds to the mean acquisition time of the seismic acquisition along transect S08 (described in Carniel et al., 2012). The two top panels show the potential temperature (Figure 2a) and salinity (Figure 2b) fields obtained by our model simulation. These fields are used as the starting point of the synthetic reconstruction of the seismic profile, i.e. we performed a "synthetic" seismic transect over the water column computed in the model. First, in situ density (Figure 2c) and sound speed (Figure 2d) fields are computed using the GIBBS Sea Water (GSW) Oceanographic Toolbox for TEOS-10 (McDougall and Barker, 2011). Then their product gives as a result the characteristic acoustic impedance scaled by 10^6 (Iz, Figure 2e) and then the normal incidence reflection coefficients R where computed (Figure 2f). Values shallower than 50 m are not considered since the configuration of seismic guns and hydrophones did not permit to record the surface layer. These computations require the determination of the variable changes over a certain depth interval; in our case we interpolate over an interval of 0.1 m all the model outputs. In the end, the reflection coefficients are convoluted with the seismic signal source (see again Carniel et al., 2012) and the obtained synthetic seismic data are shown in Figure 3, superimposed
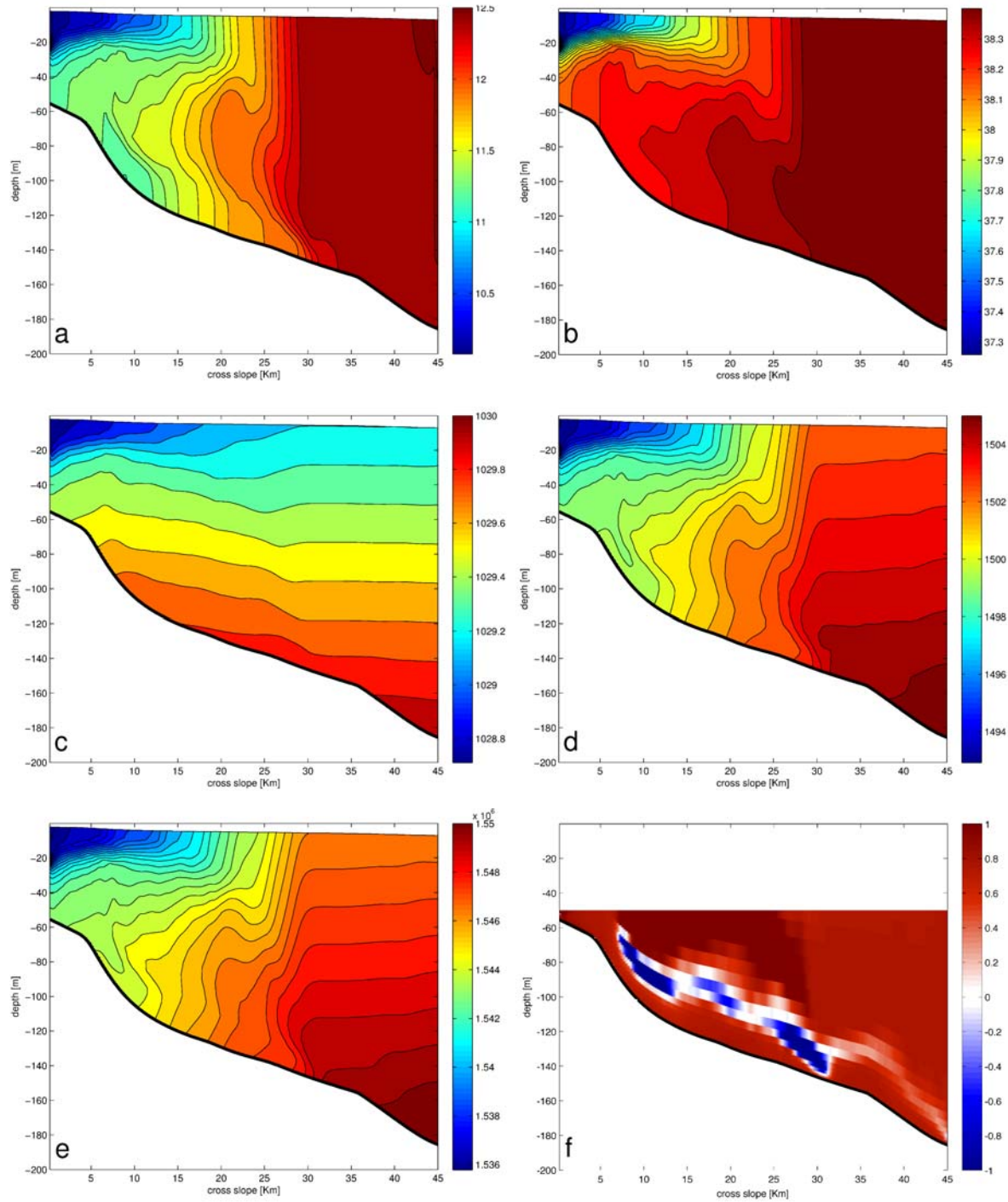
FIGURE 2. Model output of the grid line relative to S08 or AS07 seismic acquisition line. Upper panels: potential temperature(left) and salinity (right). Central panel: in situ density and sound speed. Lower panel: acoustic impedance and acoustic reflectivity.

to the density anomaly (Figure 3a) and potential temperature (Figure 3b) and show a very good agreement with the measured seismic profile (Figure 4).
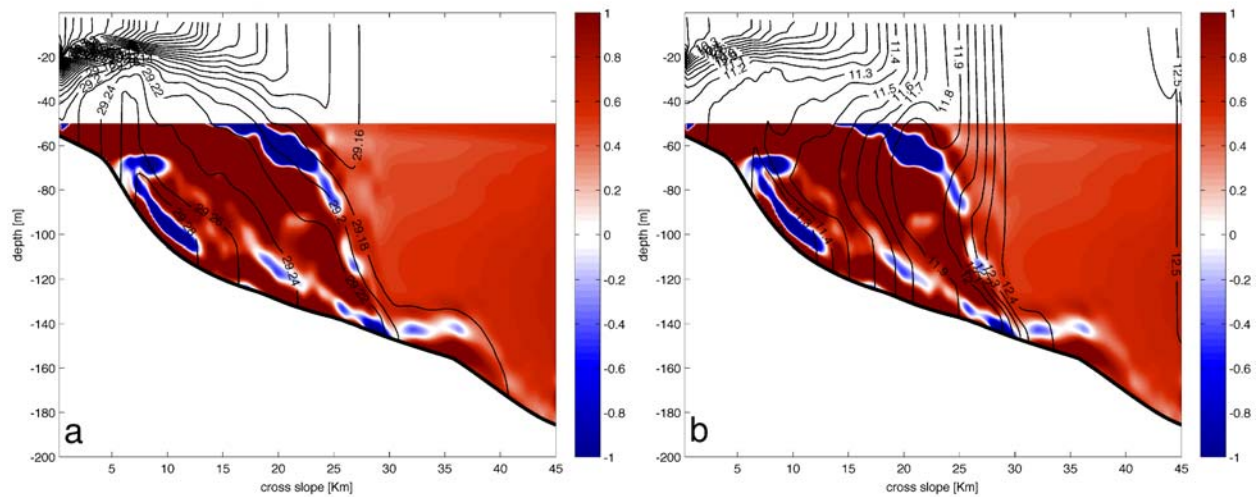
FIGURE 3. Comparison between synthetic seismic line (color field, obtained by the convolution of reflectivity, figure 2f, with the seismic source wavelet) and: density anomaly 0 (kg/m3, panel a); potential temperature (°C, panel b).
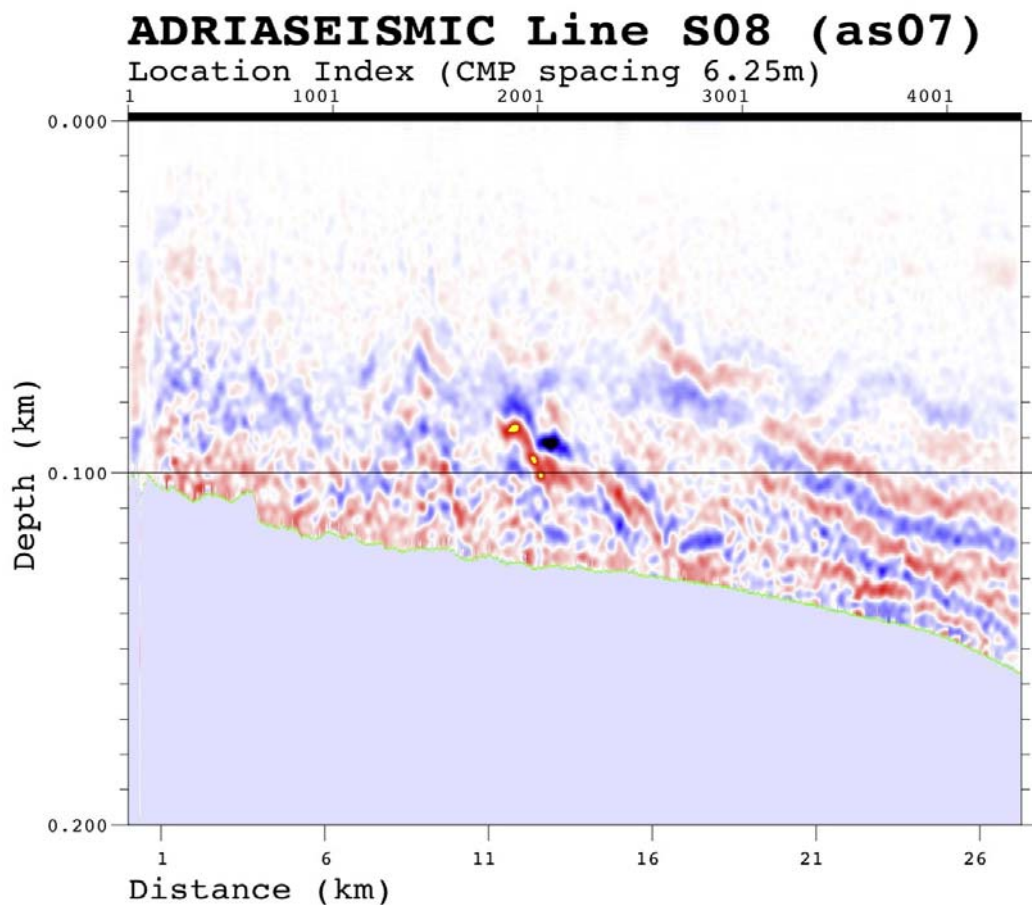

FIGURE 4. The seismic reflection for transect S08

Considerations and Future Implementations

The procedure followed shows that a direct integration between SO measurements and a fully 3D high resolution hydro dynamical numerical model results is possible and can help to provide a better frame to understand seismic oceanography data; more specifically, the agreement between reconstructed seismic lines and density anomaly field is remarkable (see Figure 3a). Moreover our results highlight the same structures reported in figure 5 from Carniel et al. 2012.

Seismic Oceanography can provide a quick and synoptic assessment of a sea section, tuning on rapid shelf-slope processes that are usually extremely difficult to detect with conventional techniques.

SO can also help to image the existing dynamical structures and their spatial/temporal resolution; on the other hand, the numerical model can quantify these acoustic snapshots in terms of temperature, salinity and density, integrating the XBTs that are acquired during SO lines, and help identifying the nature of other processes (e.g. turbulence, internal waves, etc.).

ACKNOWLEDGMENTS

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